

# A serious game to parameterize Bayesian networks: Validation in a case study in northeastern Madagascar

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## ABSTRACT

The management of multi-use landscapes is challenging, but essential when aiming at preserving the potential for ecosystem service provision. Land-use decisions lay at the center of this challenge. While land-use decision models may help to transparently grasp land-use decisions, the parameterization of such models is difficult as human decision-making is often not rational. We show here how we used a serious game to parameterize a Bayesian network-based land-use decision model. To elicit validation, game outputs are transformed to conditional probabilities and compared to conditional probabilities parameterized via a questionnaire and workshop exercises. The analysis of four types of validity shows encouraging results for criterion, respondent-related and practice-related validation. However, content validation (sensitivity analysis) was disappointing initially. We discuss how the success in validation quality may be related to the design of the game and conclude that the transfer from a game to Bayesian networks could improve the parameterization quality.

## 1. Introduction

Globally, preserving forests and their potential for ecosystem provision is seen as a central challenge for sustainability (Lambin and Meyfroidt, 2011). In Madagascar, the search for strategies to sustainably protect forests, including the perspectives of local actors and their livelihood needs, led to a shift from strictly conserved forest areas to multi-use sites (Gardner et al., 2013). In multi-use sites, land-use decisions are central to land-use and landscape changes influencing the state of a socio-ecological system (McGinnis and Ostrom, 2014); hence, land-use decisions are key when defining such strategies and frame the trade-offs among different land-use types, such as upland rice, paddy rice, and agroforestry systems.

However, land-use decisions are made following rationales and heuristics which are difficult to grasp (cf. Pahl-Wostl, 2007). Among others, individual preferences and mental models are introducing complexity into land-use change (LUC) processes, as they cannot be fully determined. In addition, interactions among decision-makers are influencing their decisions and social networks have an impact on individuals' decisions (Isaac and Matous, 2017; Manson et al., 2016). As personal preferences may alter the development of a parcel, and subsequently a farm and a landscape, these individual decisions are of

particular importance whenever a landscape management problem is approached (Blanco et al., 2017; Primdahl and Kristensen, 2011).

In such landscape management processes, we need methods supporting local actors' self-evaluation. A possibility for making land-use decisions more tangible and for considering them in landscape management is the development of land-use decision models. However, their ability for prediction is by no means a revelation of truth but rather an approach to make possible decision-making rationales explicit. Modeling helps clarify land-use decisions and their inherent trade-offs.

Land-use decisions and related trade-offs may be captured in a serious game. We use the term *serious game* to reflect that, besides the joyful part of a game, a game may be used for learning, instruction, or deliberations of challenges (Wouters et al., 2013). According to Wouters and colleagues, characteristics of a game are interaction, agreed upon rules, goal-orientation, often in connection with a challenge, and the provision of feedback. These characteristics are applicable for analog games, too. Additionally, for role-playing games (RPGs), participants adopt specific roles.

In the iterative development process, the game was inspired by other serious games in the broader field of land system science. Cleland et al. (2012) used a game board with cards representing the characteristics of a location or livelihood options to explore interactions in subsistence

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fishing communities. [Salvini et al. \(2016\)](#) aimed at showing the learning effect of a game and induced the effects of “sustainable” management in the game, demonstrating its effect. [Villamor and van Noordwijk \(2011\)](#) designed a game including villagers and external agents (providing financial incentives) and let them interact in the context of forest conservation and management. Similar to many other game approaches, they introduced exogenous changes (i.e. population increase, forest fire, rubber price decrease) in the rounds of the game.

The potential added-value of combining a game with a computer-based model was recognized by the Companion Modeling community ([Étienne, 2014](#)) and their extensive use of agent-based models (ABMs). The RPGs may be designed after the ABM existed ([Campo et al., 2009](#); [Castella et al., 2005](#)) or before ([Salvini et al., 2016](#)). In the latter case, the transfer from the game to the ABM was based on the choices played in the game. Thus, model mechanisms could be iteratively calibrated and validated with the help of a game.

The main research needs are related to the translation from a game to a computational model and the challenge grasping often intangible decision-making processes. In many publications, the transfer from a role-playing or tabletop game to a computer model has not been specified in more detail. [Barnaud et al. \(2013\)](#) even distinguishes between the computer model producing scientific knowledge and the game aiming at facilitating communication. However, both, a well-defined transfer from a game to a computer model and the production of scientific knowledge with a game, help to ensure credibility of such processes.

[Mallampalli et al. \(2016\)](#) compared 10 methods helping translate narrative scenarios to quantitative models. While both the Bayesian network (BN) and RPGs are seen as such a translation method, a possible combination of these two approaches was not mentioned. They suggested RPGs to be most compatible with an ABM. Here, we would like to consider the usefulness of combining RPGs with BNs, using the ability of games to reveal insights that rarely emerge in interviews ([Pak and Brieva, 2010](#)).

To combine a serious game with modeling is regarded as advantageous as in-depth deliberation in the game may be combined with the forecasting capabilities of a modeling exercise ([Barreteau et al., 2001](#); [Voinov et al., 2016](#)). Here, we focus on the nexus between a game and our modeling tool which is a BN. More specifically, connecting a game to our BN seems promising, as game participants bring their habits and mental models with them to the game, and we can elicit participants' system knowledge taking into account their ideas and intentions ([Castella et al., 2005](#); [Lamarque et al., 2013](#)). In addition, RPGs may help to jointly define the problems to be addressed ([Pak and Brieva, 2010](#)).

We test a serious game, which mimics land-use (change) decision-making. Participants play multiple rounds to explore different

scenarios, and the results are used to parameterize a BN node. Methodologically, we describe a connection that was—to the best of our knowledge—not made until now. This paper focuses on the transfer from a tabletop RPG to a computer model. The paper aims at making this procedure transparent and critically reviewing the added-value for the specific case of BNs. Hence, evidence for reliability and validity of this transfer needs to be presented. We would like to answer the following question: How valid is the presented game as a method to parameterize a BN?

## 2. Methods

### 2.1. The game

In this research and learning game ([van den Hoogen et al., 2016](#)) players cultivate land in order to achieve a good living for the household. In the game, local actors were confronted with land-use decision situations. Players had to allocate labor force units to their land-use portfolio. Therefore, we called the game “sandry game” as “sandry” in the local Malagasy dialect means “labor force” and strength of a person to create something. The allocation of labor force units (pawns in the game) served as a proxy for the players' intentions. The game set-up was based on field data, observations gained through field missions, discussions with Madagascar experts, as well as trial and error to adjust game mechanisms. [Fig. 1](#) shows the game set-up (left), players and the tokens for cloves and vanilla as well as the fake money (top right).

Three possible roles were attributed to the players: (a) Four farmers were the key actors of the game. They made labor force decisions by allocating labor force units to available land-use plots. The farmers were characterized by available land-use plots and household size, both of which varied in number. However, the money available was the same for all farmers. These characterizations were based on real life situations but adapted to a game situation by reducing complexity (e.g., biophysical mechanisms, number of land-use categories) and increasing wealth of underprivileged roles to increase playability. Others classified households in a neighboring region in more detail, but similarly ([Laney and Turner, 2015](#); [Zaehring et al., 2017](#)). They used farming area per household, the number of commercial plants, income from cash crop production, production of rice and others to create household groups. (b) The collectors are a type of intermediary actor, who buys cloves from villages and sells them to a next level of the value-chain. In the game, they sell cloves directly to the exporter. Two collectors sell to the same exporter. For vanilla, markets are organized in central villages and prices are determined by the world market (= game coordinator). The game coordinator is buying vanilla directly from farmers at a standard,



Fig. 1. Game setting in a four-player set up.

but varying, price. For cloves, collectors visit each household to buy the harvest. (c) The role of the exporter is scripted and played by a game facilitator. In the game, the exporter is responsible for the demand of cash crops and has capital stock to buy all the cloves on the market. The exporter discusses contracts with collectors. Exporters receive demand and price signals from the world market (the game coordinator secretly provides this information).

In the first year, a normal (average) season was revealed to participants. The characteristics of the subsequent seasons followed a sequence confronting farmers with a theft, a cyclone, a season with good yields, a pest, and three average seasons, in which only market prices for cash crops would change.

The labor force allocations were recorded in an Excel sheet after each season. In other words, the number of pawns for every land-use parcel players cultivated were recorded. Each game session ended with a debriefing session to reflect on the victory condition, the degree of reality, and the strategy played by participants. After each year, all participants had to complete an annual accounting and report to the game coordinator the amount of crop stock and the amount of money. Additionally, players reported whether they want to send children to school and lastly, they were asked to rate with a sign of their thumbs their overall satisfaction with their current game performance. The full game lasted between 3 and 3.5 h, playing three years with two seasons each.

The thin red line between being close to reality and at the same time enable playability was constantly reflected within the larger research team and in the debriefing of the game. To reflect on this challenge, we analyzed the game and its output to demonstrate the prototypical transfer of the game data to a conditional probability table (CPT), and to compare the parameterization from the game with other data sources, i. e. questionnaire and workshop outputs.

## 2.2. Bayesian networks and the land-use decision model

BNs are directed acyclic graphs. Network nodes represent variables and arcs represent causal relationships. All nodes and their relationships are specified with CPTs. The Bayesian rule of conditional probability is applicable to infer posterior probabilities. Focusing on two nodes in a BN, posterior probability is calculated via  $P(x|e) = P(x) * P(e|x) / P(e)$ , where  $x$  is the probability of a parent node state and  $e$  is the evidence of a child node state. To solve an entire network structure, chain rule is applied (e.g. for three nodes in a BN equation  $P(A,B,C) = P(A|B,C) * P(B|C) * P(C)$  shows the chain rule and determines the network structure). Next, marginalization or variable elimination “allows us to remove variables from a joint probability distribution” (Jensen and Nielsen, 2007, p. 10) as all possible probabilities of one variable are summed up to determine the marginal contribution of another. In BN solving, marginalization helps to efficiently determine posterior probability. Using the (conditional) independence properties (or equivalently the directed, global Markov property) in a BN increases efficiency as factorization of distributions into distributions with lower dimensions is possible (Kjaerulff and Madsen, 2008). Algorithms based on the Bayesian rule are used in software that provides graphical user or application programming interfaces (Jensen and Nielsen, 2007; Kjaerulff and Madsen, 2008; Norsys, 2011). With these types of software, entire network structures can be calculated. We used Norsys Netica

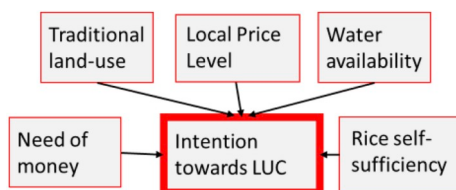


Fig. 2. Cut-out of the Bayesian network structure displaying all parent nodes to the focused node “intention towards land-use change (LUC)”.

(version 5.18, 64 bit).

The game gave us input to one specific and central node in the BN called “land-use intention”. Compared to ABM approaches, our game does not mirror the computer model (or vice-versa). We rather use the game (a) to inform one node in the BN and (b) to create a learning environment for participants and researchers.

The BN reflects LUC decisions and the mentioned central node “land-use intention” is the child node that captures influence factors a farmer takes into account optimizing his farm level decisions. “Land-use intention”, in turn, is parent to the actual land-use category at plot level that is influenced by biophysical characteristics and policy or regulations. This structure is strongly motivated by Isaac Ajzen’s Theory of Planned Behavior (Ajzen, 1991) and the BN is linked dynamically to spatial data (Celio et al., 2012, 2014). The full BN is shown in Appendix B.

The model is used to predict LUC and to show different time steps of land use in a spatially-explicit manner. The BN was set-up in a participatory process involving farmers in our study sites and land-use experts in the district capital of Maroantsetra. The produced maps are intended to support strategic decision-making at village level in regard of dynamic cash crop markets and nearby protected areas.

For parameterization, we used two approaches: (a) expectation-maximization (EM) learning and (b) workshops to get knowledge on key CPs in the tables. We used Netica’s EM algorithm to learn conditional probabilities as it is viewed as more robust than “gradient descent” (Norsys, 2011). Before learning, all probability distributions are uniform. For learning, we used two case files derived from a questionnaire conducted in FV3 that collected data on land use and land-use decision-making. We first used the farm level data ( $N = 71$ ) and in a second step the plot level data ( $N = 171$ ) for learning.

## 2.3. Transfer from the game to a BN

To establish a transfer from the game outputs to the BN node intention, we used the game as an arena where certain conditions were set and land-use decisions were made. Hence, we gained knowledge under conditions framed in the game scenarios. Fig. 2 shows the conditions that needed to be controlled in the game.

“Need of money” referred to the perception whether gained money is sufficient to cover daily needs, “traditional land-use” reflected the self-conception of the households dominantly cultivated land use, “local price level” reflected the clove price, “water availability” referred to the sum of precipitation and irrigation possibilities, and “rice self-sufficiency” showed how many months per year a household is rice self-sufficient. Due to different player characteristics and game scenarios all (except one price level) states of the parent nodes could be covered.

Table 1

Research questions, validation perspective, and hints regarding methodology.

Research questions (Sub-question)	Validation perspective	Methodology
Is the land-use decision-making in the game similar to interviews or workshop “measures”?	(A) Criterion validation	Comparison of outputs from the game and triangulation methods “questionnaire” (1) and “workshop” (2).
Does the game capture all major dimensions of LUC decision-making?	(B) Content validation	(1) Sensitivity analysis to check for game driving forces in land-use decision. (2) Post-game interviews focusing on the victory condition.
Is the game an appropriate tool to elicit LUC decision-making?	(C) Respondent-related validation	(1) Analysis of consistency in game behavior and strategy statements in post-game interviews.
Is the game of use for research and the participants?	(D) Practice-related validation	(1) Content analysis of discussions regarding the degree of reality.



However, the number of game sessions was too small to cover all the state combinations.

In the game, participants placed their pawns on different land-use plots. This number per specific land-use was used as an input to calculate our proxy for conditional probabilities (Formula 1 and 2). We assumed that the revealed intention in the game may be transferred to conditional probabilities. Labor input per LU type was adjusted by the total number of plots in this category and normalized with the sum of these ratios per land-use type (normalized labor intensity).

*Labour Intensity  $LI_c$  (Formula 1) :*

*Normalized Labor Intensity  $nLI_c$  (Formula 2) :*

$$LI_c = \frac{\text{Sandy Input in Category}}{\text{Plots in Category}} = \frac{I_c}{P_c} \quad nLI_c = \frac{LI_c}{\sum_{c=1}^C LI_c}$$

We played five game sessions that were judged to be valid (three times six seasons and two times four seasons). Sixteen players' labor force allocations were analyzed for seasons one to four, and nine for seasons five and six. The calculated normalized labor intensity is equal to  $P(X|e)$  and reflects one CP in the CPT "intention". We obtained 82 seasons (or probability distributions for one set of conditions). Due to overlap of identical conditions, we averaged entries from identical sets of conditions and deduced 28 final probability distributions.

## 2.4. Methods for validation

As validation is interpreted from different perspectives (Bowen, 2008), a clear framing for this study is needed. In order to adopt a broader view of validation (Bowen, 2008), we present evidence for validity (1) showing that the scores obtained from the game accurately reflect the land-use (change) decision-making and (2) showing the usefulness of the scores obtained from the game (Bowen, 2008). Land-use (change) decision-making is captured by the game and thereon based scores. Therefore, we pose sub-questions to the abovementioned guiding question, which are related to different perspectives of validation (Table 1).

Validity "focuses on how accurately and completely a measure captures its target construct" (Bowen, 2008). To validate the quantitative inputs from the game, we used the above-mentioned debriefing of game participants and, in addition, a workshop exercise we called "imagine-exercise" as well as questionnaire data, which are used as parameterizing methods for the overall BN too. For each of the research questions we used a specific procedure that was also related to specific perspectives on validation: (A) Criterion validity was evaluated by comparing if measured scores (the game LUC decision-making) were related to scores from other measures "of the same construct" (LUC decision-making measured in questionnaire and in workshops). (B) Content validation aimed at evaluating if all dimensions "of a construct" (the LUC decision-making) were captured. (C) Respondent-related validation analyzed if content and format of a measure (the game) was appropriate to caption the players' LUC decision-making. (D) Practice-related validation evaluated whether scores (the game LUC decision-making) were relevant to LUC decision-making in reality and relevant to fill a knowledge gap of the target group (Bowen, 2008). In the results section, each result is accompanied by paragraphs contextualizing the results as this information helps to understand the elaborated validation results. In the following, we will explain the methods for each of the four different perspectives of validation in detail.

### 2.4.1. Criterion validation: comparison of outputs from the game with triangulation methods "questionnaire" (1) and "workshop" (2)

(1) Using questionnaire data: A farmer questionnaire provided data for parameter learning of the BN. For each node included in the network, we gathered farmer characteristics. The analysis applying Chi-Square test and ANOVA on the questionnaire data revealed that "water

availability" and "traditional land-use" were not significantly related to "intention". Hence, we removed these two nodes from the BN for this analysis. To be consistent, we also adapted the CPT of the game for this analysis and removed these two nodes. From the 82 player seasons (rounds and players) played, we aggregated identical condition settings and obtained 14 distinctive CP-distributions to compare with the respective CP-distributions learned from the questionnaire data.

To compare the game LUC decision-making with the questionnaire, the answers of the questionnaire were classified according to the node states. We could use 71 cases on farm level and 171 cases on plot level for EM learning that reflected the empirical combinations of "intention" and the three remaining parent nodes ("need of money", "local price level", "rice self-sufficiency"). In a next step, the obtained conditional probability entries in the CPT for the node intention could be subtracted from the conditional probability entries obtained via the game and we displayed the 14 CP that we compared in a boxplot.

(2) Using workshop outputs: In workshops we conducted a specific exercise, which we called "imagine-exercise". The aim of the imagine-exercise was the elicitation of conditional probabilities by evoking typical situations of farmers in that region. Members of the stakeholder-platform were asked to respond to the following type of questions: "Imagine 10 households in geographically lower levels of the district (e.g., Mahalevona) and these households are not indebted. Water availability does not pose any difficulties and the family produces enough rice to be rice-sufficient all year long. The price of cloves is at the level of 2015. (a) What is the intention of the majority of the households in this situation? The five possible intention categories are "more paddy rice", "more upland rice", "more pasture", "more pasture & clove", and "more agroforestry system". (b) How many of these 10 households would have this identical idea/intention? Combining the answers of questions (a) and (b) allowed us to determine a conditional probability entry for the node "intention". We repeated this procedure for an additional four times changing condition each time one to obtain a comparison dataset. The imagine-exercise was conducted with eleven members of our regional stakeholder-platform that is reflecting and consulting on the project's plans and results. This group consisted of agriculture experts such as farmer representatives, farmer cooperatives, farming consultancy NGOs, as well as district representatives of forest and agriculture. This exercise was analyzed by summing up the estimated household counts with the same decisions over all participants and normalizing them over the five possible land-use intentions. Hence, we obtained a conditional probability estimate for five conditional probability distributions.

### 2.4.2. Content validation: (1) sensitivity analysis to check for game driving forces in land-use decisions. (2) post-game interviews focusing on victory conditions

(1) Sensitivity analysis: Via the game, we specified 28 CPT-entries and all conditions were checked for their influence on the CP. To do so, the mean over all CPT-entries with the same varying condition (e.g. price, rice self-sufficiency, etc.) per land-use categories were calculated. Thus, by comparing these means, we obtained the influence of one varying condition on the game LUC decision-making. For example, looking at the intention "more paddy rice", the mean of all CPs given a local clove price of \$5.5–6.5 was compared to the mean of all CPs given a local clove price of \$6.5–7.5.

(2) Post-game interviews: After the game sessions, group debriefings were conducted. The game did not focus on winning; however, competition was part of the game. The triggering question was: Who won the game and why? This question triggered discussion and reflections on the victory condition. Answers were recorded, transcribed, and content analyzed. In total, 18 participants of six game sessions discussed the questions.

#### 2.4.3. Respondent-related validation: analysis of consistency in game behavior and strategy statements in post-game interviews

With this validation step, we determined if the game is an appropriate tool to elicit LUC decision-making. To do so, players were asked in the debriefing of the game sessions in a person-to-person interview what their game strategies were. These statements were compared to their actual decisions in the game, i.e. their allocation of labor force units to the different land-use categories. Their preferred land-use category was approximated by determining the highest probability of a land-use intention over a game session. We could distinguish (1) whether players were consistent in their statement and in their game decision-making or not (observation of game play) and (2) whether the content of the statement aligned to their actual game behavior or not (self-declaration of game play).

Fully consistent players precisely pointed out a certain strategy (e.g., optimizing for cash crop production in their statements, and this strategy could have been recognized in their game decisions. Marginally inconsistent players formulated either their strategy ambiguously or their game decisions allowed interpreting a certain range of strategies (without specifying that the strategy was diversification). Inconsistent players were contradictory, e.g., stating that their strategy was focused on cash crop production, but showing a clear priority for paddy rice in their game decisions.

#### 2.4.4. Practice-related validation: content analysis of post-game group debriefing

During the group debriefing (mentioned in 2.5.2), we also asked questions about the degree of reality of the game. The questions triggered discussions and reflections on the degree of reality which is also called “external validity” in game settings (van den Hoogen et al., 2016).

Two triggering questions were used in this discussion: (a) How do you judge the degree of reality concerning productivity increase through labor force intensification? (b) How do you judge the degree of reality concerning the implementation of soil fertility in the game? In total, 18 participants of six game sessions discussed the questions. Discussions were recorded, transcribed, and content-analyzed. We evaluated how the participants judged on the game mechanisms and how they perceived these mechanisms in reality.

#### 2.5. Study area

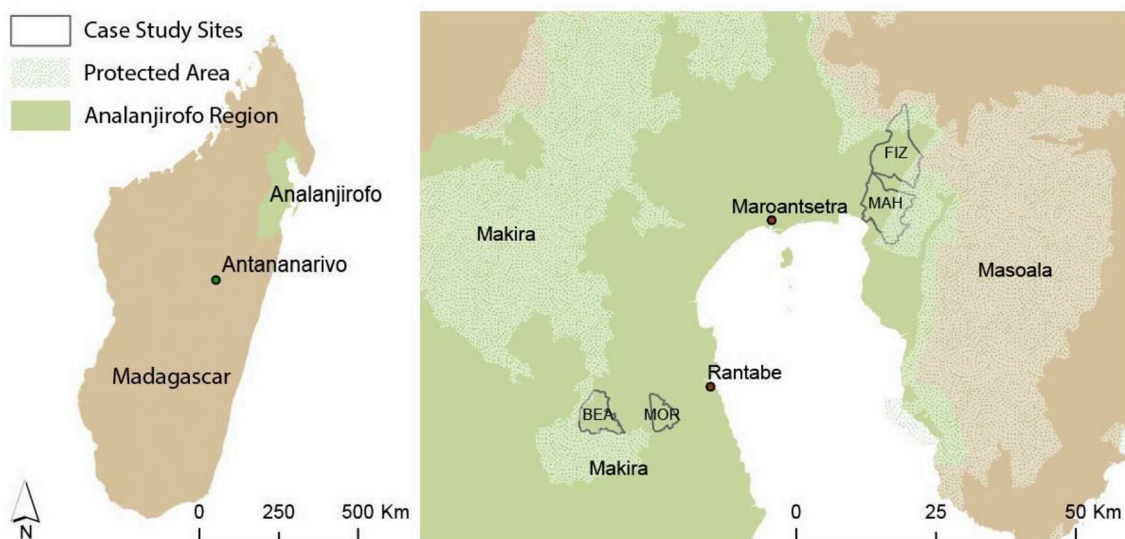
This study belonged to a six-year research project that aims to collaboratively define and test strategies for securing ecosystem-services and develop local livelihoods. The study areas were chosen enabling comparison between the study areas in Laos, Madagascar, and Myanmar. Here we report from the study area located in northeastern Madagascar where trade-offs between land-use categories are pronounced as this area is situated between two major protected areas (Makira Natural Park and Masoala National Park) (Fig. 3). This area is judged a hotspot of biodiversity (Ganzhorn et al., 2001). Hence, many existing publications shed light into the ecological system (e.g. Andrianjakarivelo et al., 2005; Merenlender et al., 1998; Rakotomanana et al., 2001). Fewer publications take an anthropological (e.g. Keller, 2008) or a combined perspective (e.g. Fedele et al., 2016; Golden and

**Table 2**

Village characteristics. More details regarding land-use categories and methodology are presented in Appendix A.

Study site (village)	Population (01-01-2016)	Main land-use shares [%] (2011)	
Beanana (BEA)	721	Mixed shifting - Forest dominated	99.9%
Morafeno (MOR)	1,889	Mixed paddy - Forest dominated	67.9%
		Mixed paddy - High-intensity tree crop	23.5%
Mahalevona (MAH)	9,834	Mixed paddy - Forest dominated	49.5%
		Paddy - High-intensity tree crop	20.0%
		Mixed paddy - High-intensity tree crop	16.4%
Fizono (FIZ)	3,851	Paddy - Forest dominated	14.0%
		Mixed paddy - Forest dominated	80.3%
		Mixed paddy - high-intensity tree crop	12.8%
		Paddy - Forest dominated	6.9%

Source: Population: Service population/District de Maroantsetra. Main land-use shares: own calculations based on Zaehring et al. (2016).



**Fig. 3.** Case study sites northeast and southwest of the district capital Maroantsetra. BEA: Beanana, MOR: Morafeno, MAH: Mahalevona, FIZ: Fizono. Data sources: Territory: GADM database ([www.gadm.org](http://www.gadm.org)), version 2.0, December 2011; Park boundaries: Système d'Aires Protégées de Madagascar (SAPM); Places: Open-StreetMap as of 2017–12-06, retrieved from <https://download.geofabrik.de>; study areas: village boundaries adapted to fit local actors' perspective based on UN OCHA ROSA (United Nations, Office for the Coordination of Humanitarian Affairs, Regional Office for Southern Africa) & NDMO/BNGRC (Madagascar National Disaster Management Office), September 2011.

Comaroff, 2015; Zaehring et al., 2017).

To test the game-BN translation, we studied a socio-ecological system (SES) in which actors (in our case: farmers) are confronted with a context of increasing complexity (cf. Seto and Reenberg, 2014). Complexity rises as global market interactions intensify through market integration (Adger et al., 2009; Liu et al., 2013), local access to land-resources becomes relatively scarce, e.g., by delimiting protected areas (Ward et al., 2018), and the mutually reinforcing mechanisms of increased financial means and locally diversified demand (for globally-distributed consumer goods).

In our study area, farmers are confronted with trade-offs between feeding a household (through subsistence rice cultivation) and earning money (through cash crop cultivation) to buy daily needs products and invest in the farm. This is a common challenge for all farmers in northeastern Madagascar (Pfund et al., 2011). Laney and Turner (2015) propose an endogenous and an exogenous view why farmers keep subsistence production. The endogenous perspective emphasizes traditions or norms, while the exogenous perspective emphasizes market imperfections or constraints. Induced by rising prices, clove and vanilla production gained a dynamic and the trade-off between subsistence and cash crop farming was emphasized in recent years.

In the region of Analanjirifo, clove cultivation has historically been and is still an important part of the agricultural sector (Danthu et al., 2014). The therein included district of Maroantsetra is a rural area with about 14% of the population living in the district capital of Maroantsetra and about 84% of the population in the district being farmers (Rasolofomanana, 2009). We concentrate on two areas, each composed of two villages in the district of Maroantsetra (Fig. 3). The northern site corresponds to the villages Mahalevona (MAH) and Fizonon (FIZ) (municipality of Mahalevona) and the southern site to the villages Morafeno (MOR) and Beanana (BEA) (municipality of Morafeno). From both case study sites, inhabitants travel about one day to the district capital called Maroantsetra.

Main land-uses in the areas are the cultivation of irrigated paddy rice, rainfed upland rice, agroforestry systems including cash and subsistence crops, and pastures for zebus (Table 2). Analyzing the landscape mosaic in 1995 and 2011, farmers in MAH developed from cultivating mostly a mixed upland rice landscape (in 1995) to a mixed paddy rice landscape (in 2011). Farmers in FIZ developed with the same pattern. However, farmers in MOR cultivated constantly a mixed paddy landscape and BEA cultivated constantly a mixed upland rice landscape in this period (based on landscape mosaic approach detailed in Zaehring et al., 2016. see Appendix A for more details).

We collected data for this study during four field visits (FVs). The exploratory FV1 took place from end of August to mid-September 2015. We visited three neighboring villages of MAH being part of a former

study to report its results. These villages were not intended to be part of the actual study sites for this study. At this occasion, we conducted 13 interviews with farmers in the villages Navana, Mahafidina, and Marofototra getting insight on their ways of cultivation and the value chain they are taking part. FV2 took place from mid-April to the end of April 2016 and aimed at setting-up a game on land-use decision-making, using interviews and four pre-test game sessions. FV3 took place from the beginning of November to mid-December 2016 and focused on playing the game and debriefing players in order to create a learning environment and to evaluate the game's potential for the parameterization of BNs. FV4 took place in February 2018 and was used to verify patterns land-use decision patterns revealed in the game session. In each site, we conducted a focus group discussion to critically discuss preliminary findings. In each group, 10–19 female (26%) and male (74%) farmers were present.

### 3. Results

#### 3.1. Is the land-use decision-making in the game similar to interview or workshop "measures"?

##### 3.1.1. Questionnaire data

The mean difference between the game and the questionnaire's CP was in absolute values from 0.03 to 0.28 (Fig. 4) for the three land-use categories which were discussed and played most often. In the actual game, paddy rice was more frequently chosen in land-use decisions made by the players than in the questionnaire (higher median by .24), while agroforestry systems (AFSs) was a less selected choice in the game, compared to the CP resulting from the questionnaire data (median .04).

**Contextualization:** We observed a high interest in paddy rice during the game sessions (compared to the questionnaire data). A primary reason for this difference could be the credo "rice is Madagascar's foundation for food security", which was frequently mentioned during game sessions.

To exclude the possibility that the different interest in paddy rice in the game and the questionnaire result from a bias due to location, we checked from which villages the data was sourced and used Zaehring et al. (2016) to check for the dominant land use in 2011. We played 12 seasons in MAH, 10 seasons in MOR and FIZ (all three nowadays mixed paddy rice-based), and 4 seasons in BEA (mixed upland rice-based). Questionnaire participants were sampled according to the relative number of the population per village. This resulted in 56 cases (farm households) based in mixed paddy rice landscapes (MAH, MOR, FIZ) and 15 cases from mixed upland rice landscapes (BEA). Thus, the trend toward rice production in the game sessions cannot be explained due to a different database (e.g., a bias due to location), but the game seems to represent the current cultivation. The intuitive game play shows rather the current strategies as the decision-making is immediate and similar to the player's operational decision-making. The questionnaire however, could be influenced by responses to assumed value-systems triggered by the interaction with the researcher.

##### 3.1.2. Workshop outputs

Table 3 shows the five decision situations brought up in the "imagine exercise," the revealed intention (as CPs), and the deviation of the imagine exercise's values from the game's values. Three times, we found a remarkably high deviation. In case two, participants in the imagine exercise emphasized the combined system of pastures with clove trees which represents a cash crop-based production. In the game, we found a relatively high probability (0.23) for pure pasture without clove trees that is categorized neither as cash crop- nor as rice-based production. In case three, the workshop participants did not consider the possible cultivation of upland rice, but concentrated on the cultivation of cash crops. Therefore, there was a shift in weight from rice-based to cash crop-based cultivation.

**Contextualization:** There is coherence in the way farmers decide in

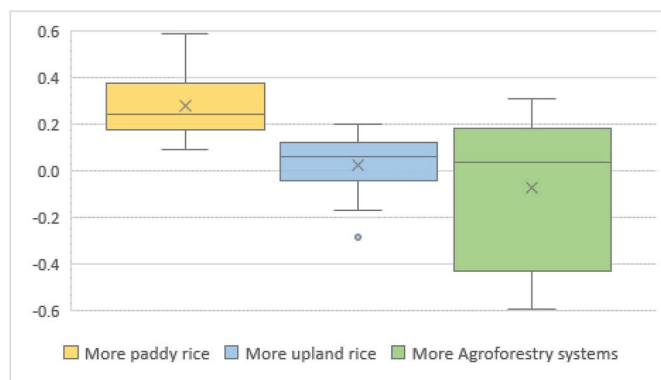


Fig. 4. Median, mean, quartiles, and outliers for subtractions with "Game Probabilities Minus Questionnaire Probabilities" differentiated according to the three land-use categories for 14 CP-distributions provided by the game. "X": Mean. Quartile calculations are exclusive median.

**Table 3**

Five cases showing decision situations, the revealed intention (as CPs) in the “imagine exercise”, and the subtraction of the “imagine exercise”-CP and the game-CP for these five situations. Rice-based: summing up upland and paddy rice. Cash crop-based: summing up mixed agroforestry and clove-focused agroforestry systems. Numbers are CP. Rationales provided in the workshop are given below the table for every case.

Case	Conditions					Intention in “imagine exercise”					Imagine - Game	
	Price	Months of self-sufficiency	Need for money	Traditional LU	Water situation	More paddy	More upland	More pasture	More pasture/clove	More AFS	Rice-based	Cash crop-based
1	6.5–7.5 (2015)	>11	No	Paddy rice	OK	0.39	0.00	0.00	0.30	0.31	−0.06	0.06
2	5.5–6.5 (2011)	>11	No	Paddy rice	OK	0.36	0.00	0.00	0.25	0.39	−0.06	0.29
3	6.5–7.5 (2015)	8–11	No	Upland rice	OK	0.19	0.06	0.00	0.23	0.52	−0.26	0.28
4	6.5–7.5 (2015)	5–8	Yes	Upland rice	OK	0.38	0.11	0.00	0.11	0.40	−0.11	0.11
5	6.5–7.5 (2015)	5–8	Yes	Upland rice	NOT OK	0.04	0.44	0.00	0.26	0.26	−0.15	0.15
<b>Case</b>	<b>Rationales in workshop exercise for having certain intentions; information provided by workshop participants.</b>											
1	The MAH village area covers part of a plain mainly used for paddy rice cultivation; hence, the village has strong roots in cultivating paddy rice. Price influences the interest in cloves and farmers reduce work for other crops. Farmers do not have debts. As farmers have enough rice, they try to increase their clove revenues. There is a trade-off between short-term revenues from paddy rice and long-term revenues from cloves. Planting cloves requires 4–7 years until a first harvest. Farmers look for pastures; zebus graze if there are weeds around clove trees. However, the production of clove trees may decrease if grazing and clove production are combined.											
2	MAH is a region with a lot of flat agricultural land; thus, farmers are cultivating paddy rice. Confronted with a clove price reduction, farmers would reduce cash crops and potentially try to increase the number of zebus. Cloves as a cultivation type do not need that much attention (compared to the cultivation of vanilla). Cloves may generate money which helps paying for school fees.											
3	Around Morafeno, farmers generally have a high interest in cash crops. If the terrain allows, farmers generally have a high interest in the cultivation of paddy rice.											
4	If they need the money immediately, they would go for upland rice. However, this usually does not provide enough money. Therefore, if farmers are in need of money, they go for AFS, as well. Mixture is important, as waiting for clove or vanilla to be ready is not possible. Due to a lack of water, farmers would turn to pasture (zebus) and cloves. As long as there is water, they would prefer rice cultivation as income is generated rapidly. In Morafeno, precious stones can be a good source of income.											
5	Farmers would rather focus on upland rice instead of paddy rice. Another possibility is concentrating on AFS.											

**Table 4**

Changing game conditions and the revealed game decisions.

		More paddy	More upland	More AFS	Rationale	
Price	State 1: \$5.5–6.5	0.41	0.13	0.42	Expected:	Higher prices lead to higher inputs in cash crop production.
	State 2: \$6.5–7.5	0.44	0.06	0.41	Found:	No effect in this direction. Rather balanced.
	State 3: > \$7.5	0.44	0.13	0.43	Rationale:	As in reality, price was revealed at the end of the season. However, players' adjustment was not very big.
Rice sufficiency	State 1: <5 months	0.43	0.17	0.41	Expected:	Higher self-sufficiency leads to reduced input in rice.
	State 2: 5–8 months	0.46	0.05	0.46	Found:	No effect or only marginal effect in this direction. Rather balanced.
	State 3: 8–11 months	0.42	0.11	0.39	Rationale:	Independent of their rice sufficiency, they would keep rice as the foundation of their diet.
	State 4: >11 months	0.38	0.16	0.39		
Need for money	State 1: Yes	0.46	0.09	0.45	Expected:	Need for money leads to higher input in cash crops.
	State 2: No	0.41	0.11	0.40	Found: Rationale:	No effect in this direction. Rather balanced. Independent of their financial situation, they keep up their rice production ("base d'alimentation").
Tradition	State 1: Upland rice	0.38	0.15	0.45	Expected:	Tradition in a certain production system stabilizes this specific way of cultivation.
	State 2: Paddy rice	0.48	0.07	0.38	Found:	Tradition has an effect on the chosen set of inputs.
	State 3: AFS	–	–	–	Rationale:	Players bring their own reality-based experiences with them and overrule the game-induced conditions.
Water	State 1: OK	0.37	0.13	0.43	Expected:	Lack of water leads to higher input in cash crops (or upland rice).
	State 2: Lack	0.54	0.05	0.40	Found: Rationale:	Higher input in paddy rice, which is counterintuitive. As water is a local phenomenon, which was not part of the game, players do not base their decisions on water characteristics.

the game and how experts think farmers decide (revealed in the imagine exercise). However, the comparison reveals a difference of about 15–20% between game decisions and estimated decisions (or intentions) by regional agroforestry and farming experts. In the imagine exercise, farming experts overestimated the intention of cash crop-based production systems compared to the game output.

### 3.2. Does the game capture all the major dimensions of LUC decision-making?

#### 3.2.1. Sensitivity analysis

To understand if the game captures major dimensions of LUC decision-making, we checked how strongly the game induced conditions



influenced game decisions. Table 4 shows the mean for all CPT entries separated by the varying conditions (e.g., price, rice self-sufficiency, etc.) and land-use categories. Thus, the table reveals how players' decisions have changed, being confronted with different conditions in the game (e.g., State 1, State 2). We focus on players' decisions regarding paddy rice, upland rice, and AFS. The last column reveals our expectations and rationale for potential divergence.

**Contextualization:** For “price,” “rice self-sufficiency,” and “need for money,” the game behavior was unexpectedly unrelated to the game-induced conditions. The price signal was revealed at the end of the year (as in reality), but players did not seem to rely on this information. We checked this non-correlation on our fourth field visit in a focus group discussion. Four discussions were held, and the farmer groups stated that, even if clove prices would decrease, they would continue planting clove seedlings. Reasons for this rationale were that this investment pays off only after 4–7 years, that they want to compensate for the lower price with higher production, and that clove trees serve as an insurance, as well as a value to bequest. For the other two conditions (“rice self-sufficiency” and “need for money”), we think participants' risk-averse thinking, following their credo of “rice is the foundation of our food security,” influenced their game behavior.

In addition, water condition did not have an influence on the game decisions. To include the water condition, each participant was asked about how they experienced water availability. This feature was surveyed for each participant referring to his or her reality at the beginning of the game. We hypothesize that this spatially-explicit location factor was not brought to the game. The strongest influence on the game decisions had the condition “traditional cultivation.” In the introductory phase of the game, players were asked what their most prominent traditional land use was. “Traditional” was framed as the production system that they used most often looking back in time for about one generation and were proud of. Their declarations indicated upland rice for MOR and BEA and paddy rice for MAH and FIZ. This traditional production system was brought to the game and players made decisions in the game according to these statements. For MOR, however, their statements contradict our analysis of the main land-use shares (see Table 2). This could mean that their declarations or their perceptions were more relevant for the game play than the actual LUC trajectories that are based on remote sensing-based analyses.

### 3.2.2. Post-game interviews

The content analysis of the group debriefing revealed that in all game sessions the players suggested players to be winners when they were well off in monetary terms. Criteria for winning were related to monetary success and to savings (high number of zebus, a lot of land, and stock of commodity). Only once education was mentioned which is related to financial means for paying school fees.

### 3.3. Is the game an appropriate tool to elicit LUC decision-making?

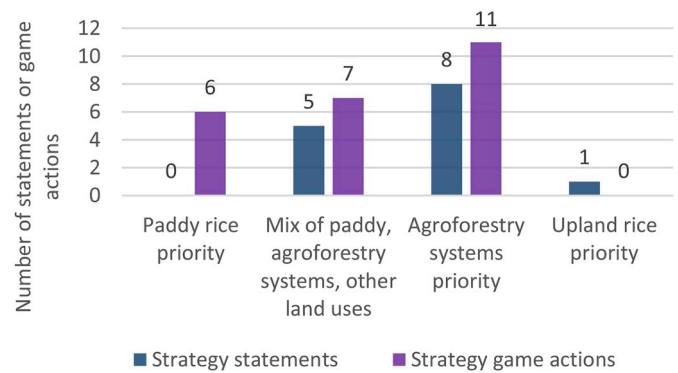
Table 5 shows that players were judged to act fully consistently or only marginally inconsistently in 82% of the cases.

Fig. 5 shows that agroforestry (including the cash crops of clove and vanilla) was the most attractive strategy in the game and that players

**Table 5**

Consistency of players observing their game play.

Consistency of players	Count	Percentage
Consistent, good performing player	6	35%
Consistent, bad performing player	2	12%
Marginally inconsistent, good performing player	6	35%
Inconsistent player	3	18%
N: One additional player, who had missing education and rice sufficiency data is included here.		17



**Fig. 5.** Content of the strategy statement and game behavior (double counting possible, e.g., with paddy rice priority and mix of paddy, agroforestry systems, and other land uses). N(statements): 25 with 8 duplicates; 17 unique cases (of one player three times used. 14 strategy statements in diagram. In addition, further strategy statements (found 11 times in total): changing cultivation (yearly adaptation), financial optimization, workforce optimization, connection to the current season, and lacking parcels. N(game actions): 24 with 7 duplicates; 17 unique. Duplicates in case of mixed preferences.

would refer to this strategy in their statements. Implementing a mixture of paddy rice, agroforestry systems, and even other land uses, such as pasture or pasture with single clove trees, was the second most frequently chosen option. Interestingly, in the game, many players focused on paddy rice (having the highest labor input for this land-use category), but nobody admitted to this strategy in the debriefing. Importantly, no player decided to invest a labor force in upland rice nor stated such a strategy in the debriefing.

**Contextualization:** In summary, farmers were not fully consistent, but their stated reflections on their strategy most often aligned with their decisions in the game setting. Hence, there was alignment between played decisions and stated strategies as the foundation of their game play. While this alignment could be seen as a pure memory test, it was, nevertheless, a test for internal validity. Even if participants only tried to remember how they played, they had to understand the game to answer consistently.

### 3.4. Is the game of use for research and the participants?

The group debriefing confirmed a relationship between productivity and labor input. Rationales to support this relationship focused on the potential delay of plant growth if labor input is too low. This delay would lead to reduced productivity. Regarding fertility, participants supported the relationship between non-cultivation and increasing fertility. Hence, to not cultivate a plot for a certain period would increase fertility. Interestingly, players did not distinguish between paddy rice and upland rice. In both cultivation types, non-cultivation for the period of one year (in the game) had led to increased productivity in the game. In general, the game was judged as being close to reality, and participants were able to play their role.

**Contextualization:** In the interviews in the neighboring villages of our case study site MAH in 2015 (see also section 2.5 Study area), the link between labor intensity and paddy rice production was an important topic. Farmers referred to their shift from one cultivation period per year to a second one. This change was triggered by increased demand for subsistence rice. However, they reported a decreasing yield, since they are now cultivating paddy rice two times per year. This relates to the abovementioned mechanism having a fallow state in paddy rice plots, as well. If, in the second season, the plot remains in a fallow state, production of the producing season is higher. In contrast, in agroforestry systems and, more specifically, in clove cultivation, labor input was not emphasized. Fluctuating yields were explained by productivity cycles inherent to clove plants.



#### 4. Discussion and conclusions

With the four validation perspectives analyzed, we could show that our game-BN link is suitable when comparing it to other parameterizing methods (criterion validation). Comparing players' actions during the game with players' strategy statements (respondent-related validation), as well as the stated degree of reality in the game, was encouraging. However, sensitivity analysis reflecting content validation was disappointing at first sight. Potentially, the game mechanisms were too subtle and embedded in a multitude of signals, resulting in an uncertain situation for the players. Game players had to cope with this. The coping strategy manifested itself in risk-reducing behavior and a focus on rice production. This reaction, however, was subconscious, as discussions were still focused on the cash crop topic, potentially fulfilling the supposed interest of the researchers. Nevertheless, there is evidence for such behavior as rice is central to the livelihoods of northeastern Madagascar (Rakotoarison, 2014).

The analysis provided insights in the game-BN connection and hence, we validated this transfer by triangulating different methods of validation. A potential next step could be the validation at the level of the land-use. However, this step is conditional to the understanding of the relationship between the game and the BN node outputs.

Observing risk-reducing behavior could be an added-value of the game, as this subconscious behavior could not be determined from the questionnaire. In contrast, a critical review must suggest ways to reduce complexity and increase the strength of the signals in the game. By doing so, we would expect more pronounced game reactions and consistent results in a sensitivity analysis. However, feedback from the participants also pointed to the fact that they recognized their decision-making situation in which complexity is an essential part. This aligns well with the diagnosis that, due to contextual influences, games may tend to more strongly support exploration than explanation (van den Hoogen et al., 2016).

To obtain higher production—independent of productivity—the expansion of cultivated land could be a strategy (Laney, 2004). However, as the resource of land is restricted in our case study area due to adjacent protected areas, a next step could be to intensify labor and/or capital input. Taking a long-term perspective on the induced intensification thesis, a next step could include higher investments (infrastructure, such as terraces and irrigation, or definition of rules for water access) (Turner and Ali, 1996). Especially in a situation in which expensive investments in technology are not an option due to missing financial means, inputs are increased within the existing strategy. Instead of innovating from a rain-fed to an irrigated rice cultivation system, farmers could increase cropping frequency (Styger et al., 2007). This non-change of cultivation technique could occur due to the (perceived) absence of alternatives.

The results of the sensitivity analysis showed that game-induced conditions had little effect on players' decision-making. We found explanations for such game behavior, but we still would hypothesize that farmers follow rising clove and vanilla prices and adjust their labor force input. Along this line, the game reveals a new perspective by asking which criteria, within the broader topic of "price development," a farmer considers and to what extent (e.g., difference in past price development, expected price development, (expected) price stability, opportunity costs, etc.). In addition, by analyzing the rationales provided by participants in the group debriefing, we found that the criteria for winning were strongly related to monetary success and to savings (zebus, land, and commodity). This leads to the conclusion that the game insufficiently triggered the monetary incentives.

Participants judged the game to be close to reality. In their statements, however, "social desirability" effects cannot be fully denied. In

addition, game designers should be cautious to not imply ready-made strategies with the game (Castella et al., 2005). We tried to avoid this by balancing the game as much as possible with the help of real data, such as prices for goods, without reducing too much the criterion of "playability," in order to not push players toward a certain direction or strategy.

Participants played the game with enthusiasm and never complained about unrealistic game settings. For all players, it was the first time they participated in such a game. We observed that the game, as a simplified version of reality, triggered reflections and discussions about the players' own farming strategies. However, starting from discussions about victory conditions and the degree of reality, we did not capture any reflections going beyond the triggered topics. Possibly, due to our questions focusing on labor input and fertility, participants felt strongly guided in their responding. A pre-game interview or focus group would have been helpful to distinguish the bias induced by the game from their rationales in their daily life. What parts of the answers in the post-game debriefing were directly a result of the game remains an open question.

Comparing the lessons learned from this study with ABM approaches using games leads to additional insights: ABM and RPGs are conceptually closely related. In both "models," rules are defined and interactions are taking place. The ABM profits by opening the black box of the model to obtain rules for parameterization. In contrast, using a game to parameterize a BN needs to conceptually and methodologically bridge a wider gap. Conceptually, we step from game rules and player behavior to a causal system. Methodologically, a translation of land-use decisions, manifesting themselves through labor input to CPs, is needed. This may add plausibility as inconsistencies are discovered. In contrast, ABM and RPGs are a close representation of each other, and flaws might remain undiscovered. Furthermore, this application provides lessons learned for other attempts to facilitate BN parameterization by methods that are more intuitive.

Further research should focus on the learning aspects of this game by monitoring several rounds and time-distant sessions, feeding back results, and inquiring into in-depth relationships with reality and their cultivation, as a few examples. Additionally, the learning experience could be increased if players reported their experiences and insights to a wider public (e.g., a sounding board). This would support researchers seeking to better understand the learning effect of serious games (e.g., Sitzmann, 2011; Wouters et al., 2013). These authors, however, focus on computer games in which social interactions are potentially less established. Here, methods are required that specifically tackle the more complex situation of "real" social interactions. Additionally, further research could investigate how multiple CPTs could be populated with the same game by including additional game elements. For example, the node "need for money" in the land-use decision BN could be elicited by implementing a bank that provides loans or grants. Translation of this game behavior to probabilities could be achieved by recording played choices and calculating percentages given the identical set of conditions.

We conclude that the applied validation measures depicted in three of four cases produced encouraging results. The content validity (sensitivity analysis) was lacking in consistency. Hence, the use of a game as a means to parameterize nodes in a BN must be further analyzed to show how complexity in decision-making in reality and, potentially, in a game may be transferred to a BN. Given that game decision-making is closely related to the actors' mental models applied in their daily life, a serious game may then help make decision-making transparent. Here, the transfer of a game to a BN may help bridge the game environment and the decision-making in reality, as the outputs of a BN-based land-use decision model may connect the game with land-use changes and reality-based maps.

## Software and/or data availability section

name of software or data set	Netica 5.18 (64 bit)
developer and contact address	Norsys Software Corp.3512 West 23rd AvenueVancouver, BC,CANADAV6S 1K5
telephone	+1-604-221-2223
fax and e-mail numbers	info@norsys.com
year first available	NA
hardware required	PC
software required	Netica
availability and cost	Free version with limited number of nodes. Commercial version: 685\$
Also for software: program language, program size; for data: form of repository (data base, files, spreadsheet)	Netica proprietary
size of archive	NA
access form	<a href="https://www.norsys.com/netica.html">https://www.norsys.com/netica.html</a>

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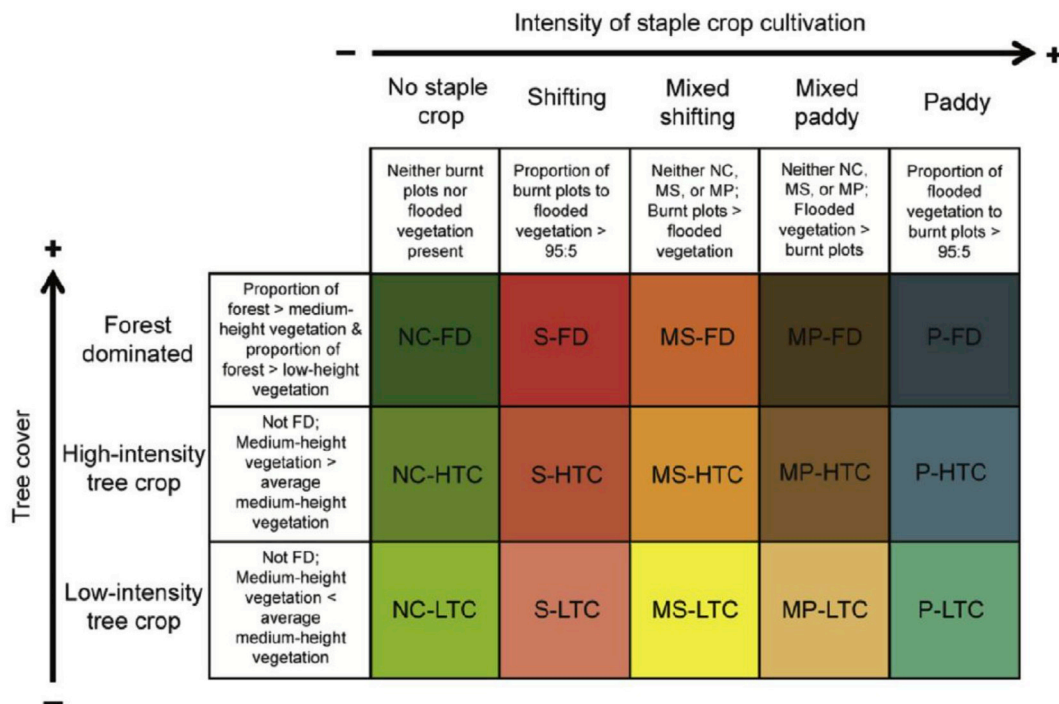
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## Appendix A. Methodology of the landscape mosaic approach

The following details are based on Zaehring et al. (2016). We summarize briefly the methodology (Fig. A-1) and explain the land-use categories used (Table A-1).

As land use cannot be directly deduced from pixel-based remote sensing data, the landscape mosaic approach interpreted pixel information by taking into account human-environmental interactions. The locational information of a pixel was interpreted in a zonal perspective including context information (i.e. the surroundings of a pixel). With the landscape mosaic approach landscape type information was provided along two gradients: (a) staple crop intensity and (b) tree cover. Subsequently, using abundance criteria in a decision-tree, each pixel in a  $5 \times 5$  km moving window was categorized along these two gradients. The basic input data were Landsat imagery land cover maps for 1995 and 2011.

Figure A-1 shows the resulting matrix of possible landscape types.



**Fig. A-1.** Landscape types categorized by staple crop intensity and tree cover. (FD = forest dominated, HTC = high-intensity tree crop, LTC = low-intensity tree crop, NC = no staple. Source: Zaehring et al. (2016).

Table A-1 shows the analysis for the four case study sites of the landscape mosaic.

**Table A-1**

Number of pixels per case study site. Pixel size  $30 \times 30$  m. Source of vector data: Zaehring et al. (2016).

	FIZONO		MAHALEVONA		MORAFENO		BEANANA	
LU-Cat	1995	2011	1995	2011	1995	2011	1995	2011
NC - FD					12		6289	
NC - HTC								

(continued on next page)

Table A-1 (continued)

	FIZONO		MAHALEVONA		MORAFENO		BEANANA	
LU-Cat	1995	2011	1995	2011	1995	2011	1995	2011
NC - LTC								
S - FD	10518		5027					2
S - HTC								
S - LTC								
MS - FD	17604		12485			380	23	15168
MS - HTC			450					
MS - LTC								
MP - FD		22586	3646	12774	3366	3009	1115	
MP - HTC		3591	4182	4239	11	1041		
MP - LTC								
P - FD		1945		3610	1012		7743	
P - HTC				5167	29			
P - LTC								

## Appendix B. Bayesian network of the land-use decision model

Fig. A-2 shows the BN structure of the BN-based land-use decision model. Grey colored nodes were controlled during the game session to determine CP of the central node “intention”. The BN has no populated CPTs included as CPTs were changing depending on the parameterization method (e.g. game, questionnaire, ...). In total, 23 nodes were used resulting in 12,108 conditional probabilities (for node definitions see Table A-3).

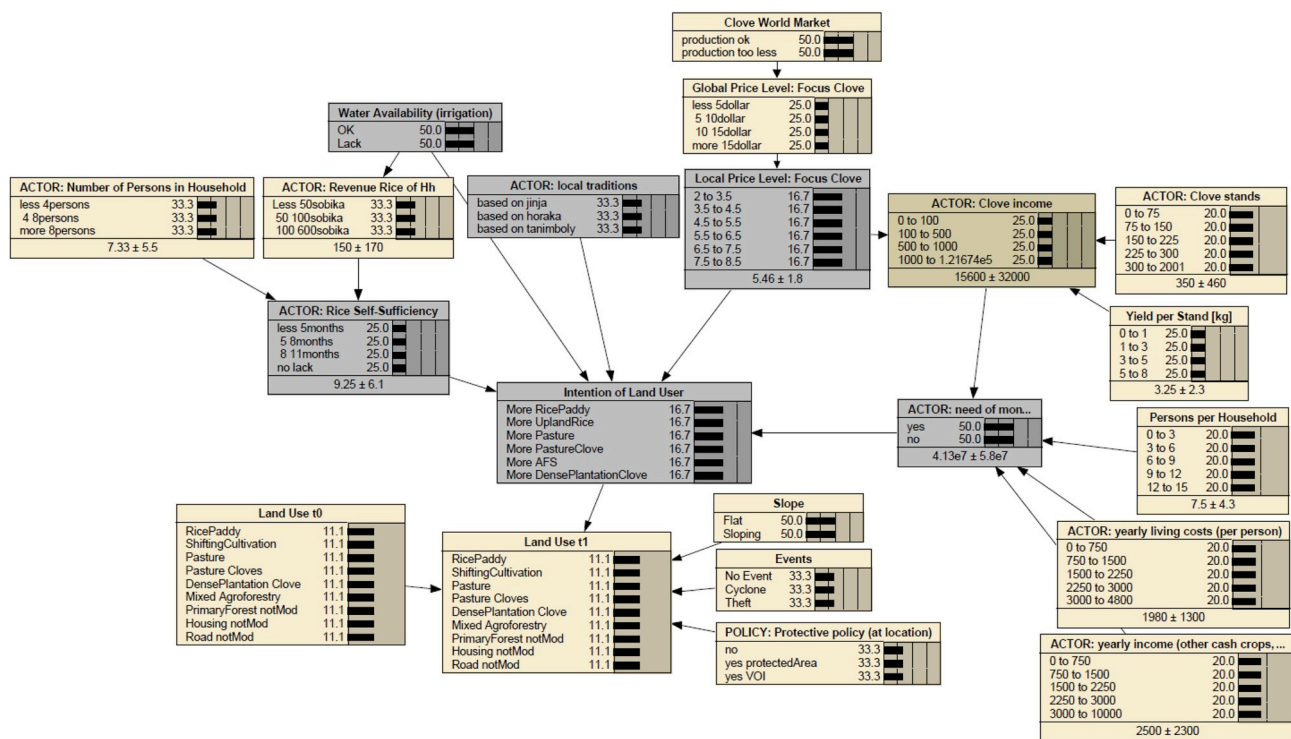


Fig. A-2. BN structure of the BN-based land-use decision model. Grey colored nodes were controlled during the game session to determine CP of the central node “intention”. BN is shown without populated CPTs as they were changing depending on the parameterization method (e.g. game, questionnaire, ...).

Table A-3 shows the node definitions.

Table A-3

Nodes and their definition

Node name	Type of knowledge	States	Definition
Land use t0/t1	No priors, using geodata for updating.	Rice Paddy Shifting Cultivation Pasture Pasture & Cloves Dense Plantation Clove Mixed Agroforestry Primary Forest (not modelled)	Land-use categories defined in collaboration with local actors and regional expert group.

(continued on next page)

Table A-3 (continued)

Node name	Type of knowledge	States	Definition
Slope	No priors, using geodata for updating.	Housing (not modelled) Road (not modelled) Flat Sloping	Flat = slop smaller than 10° Sloping: slope higher than 10°
Events	No priors except that discussion were held under the assumption that there is no theft or cyclone.	No Event Cyclone	Shows the case of events.
Water	Priors from questionnaire	Theft OK Lack	Aggregated water situation including precipitation and irrigation systems.
Protected area	No Prior except that discussion were held under the assumption that there is no protected area where farmers cultivate.	no yes: protected Area at this location yes: community forest (VOI) at this location.	Strongly protected areas such as national parks or nature parks (Makira or Masoala) and community forests (VOI) influence land-use decision-making. Given such an area, the
Revenue	Questionnaire priors	Less than 50 sobika 50 - 100 sobika 100 - 600 sobika	Total amount of rice produces in one household. Measured in sobika (1 sobika = approx. 15–20 kg = 30–48 l).
Living costs	Questionnaire priors	Continuous. Discretized.	Living costs including rice, schooling, medical expenses, transportation and other expenses of daily needs. Reference: Yearly living costs: 2–3 kapoaka rice/day = 1000 Ariary. Value of rice per year: 365000 Ar = 120 \$.
Yearly income from other cash crops (such as vanilla, coffee)	Questionnaire priors	Continuous. Discretized.	Cash income from cash crops (vanilla and coffee) other than cloves. Reference: Local vanilla price in 2017.
Clove price farmer (at farm gate)	Questionnaire prior	Continuous. Discretized.	Clove price per kg at local level (farm gate) in dollar. Reference: Clove price reached 20'000 Ariary/kg in 2017 (approximately 5.6–5.9\$).
Clove price global market (export price)	NO DATA	Continuous. Discretized.	Price at the exporter in Madagascar (in dollar per kg).
World	NO DATA	over supply over demand	Status of world clove market. Taking into account major producers, importers and exporters a supply/demand ratio reflects the potential push of the clove's market price.
Yield per stand	Questionnaire prior	Continuous. Discretized.	Cloves harvested from one tree. Proxy to estimate total amount of cloves harvested. References are varying strongly: an average seem to be 1–3 kg per tree. Equation: Price * Yieldperstand * stands
Clove income	Intermediate with equation	Continuous. Discretized.	Equation: yearlyincome_other_cc + cloveincome + yearlyincome_other - (livingcosts * personshousehold)
need for money	Intermediate with equation	Continuous. Discretized.	Comparing the number of persons with the rice revenue to estimate how many months a household may eat their own rice.
Rice (self-)sufficiency	Intermediate with EM learning	Continuous. Discretized.	Number of persons in the same household (supported by the same "chef de ménage").
Persons	Questionnaire prior	Continuous. Discretized.	Number of persons in the same household (supported by the same "chef de ménage").
Persons perhousehold	Questionnaire prior	Continuous. Discretized.	Number of persons in the same household (supported by the same "chef de ménage").
Stands	Questionnaire prior	Continuous. Discretized.	Number of clove trees a household has.
Tradition (cultivation, production)	No prior	based on jinja (shifting cultivation) based on horaka (paddy rice cultivation) based on tanimboly (mixed agroforestry)	Village-based indicator. Depending on the location, a different tradition applies.
Intention	Intermediate with EM learning	More Rice Paddy More Upland Rice More Pasture More Pasture Clove More AFS More Dense Plantation Clove	Intention motivated by Ajzen's theory of planned behavior (Ajzen, 1991).

## References

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